

RECOMMENDATION ITU-R S.1521

Allowable error performance for a hypothetical reference digital path based on synchronous digital hierarchy

(Question ITU-R 75/4)

(2001)

The ITU Radiocommunication Assembly,

considering

- a) that satellites operating in the fixed-satellite service play an important role in providing reliable international digital communications;
- b) that satellite link performance must be sufficient to allow compliance with overall end-to-end performance objectives and in turn end-user quality objectives;
- c) that satellite link performance is generally distance independent;
- d) that Recommendation ITU-R S.1062 specifies satellite link performance objectives which comply with the objectives specified in ITU-T Recommendation G.826;
- e) that the error performance for international constant bit-rate synchronous digital paths which are intended to carry asynchronous transfer mode (ATM) traffic as defined in ITU-T Recommendation I.356 has been specified in ITU-T Recommendation G.828;
- f) that in defining error performance criteria, it is necessary to take into account all error-inducing mechanisms, especially time-varying propagation conditions and interference;
- g) that satellite systems can be designed to meet a wide range of performance requirements,

recommends

1 that satellite links within the public network and intended to carry synchronous digital hierarchy (SDH) and ATM traffic should be designed to at least meet the specifications set forth in this Recommendation which is based upon ITU-T Recommendation G.828;

2 that the methodology explained in Annex 2 should be used to generate the necessary bit error probability (BEP) design masks, see also Note 2. To fully comply with ITU-T Recommendation G.828, the BEP divided by the average number of errors per burst (BEP/α , see § 3 of Annex 2) at the output of either end of a two-way hypothetical reference digital path (HRDP) should not exceed, during the total time including the worst month, the design masks defined in Table 1 and also in the BEP masks given in Fig. 2 in Annex 2;

TABLE 1

Bit rate (kbit/s)	Percentage of total time (worst month)	BEP/ α
1 664	0.2	1×10^{-9}
	2.0	1×10^{-9}
	10.0	1×10^{-9}
2 240	0.2	1×10^{-9}
	2.0	1×10^{-9}
	10.0	1×10^{-9}
6 848	0.2	1×10^{-9}
	2.0	7×10^{-10}
	10.0	6×10^{-10}
48 960	0.2	1×10^{-9}
	2.0	2×10^{-10}
	10.0	1×10^{-10}
150 336	0.2	1×10^{-9}
	2.0	2×10^{-10}
	10.0	9×10^{-11}
601 334	0.2	To be determined
	2.0	To be determined
	10.0	To be determined

3 that the following Notes are a part of this Recommendation:

NOTE 1 – The HRDP referred to is specified in Recommendation ITU-R S.521.

NOTE 2 – The BEP ratios given in Table 1 could be estimated by a bit error ratio (BER) measurement taken over a sufficiently long period of time. A method for measuring BERs as a function of a shorter percentage of time is given in Annex 1 of Recommendation ITU-R S.1062.

NOTE 3 – For ease of application, the values given in Table 1 are in terms of total time and represent the limits of a BEP performance model utilizing the method outlined in Annex 2. In arriving at the figures in Table 1 the errors occurring during the unavailable time have been excluded. The BEPs in Table 1 are not the only ones that meet the requirements of ITU-T Recommendation G.828. Other BEP masks may be used where appropriate to satisfy ITU-T Recommendation G.828.

NOTE 4 – This Recommendation applies to satellite systems operating below 15 GHz. The extension to systems operating at higher frequencies is the subject of further study.

NOTE 5 – A BEP value of 1×10^{-8} has been used as the unavailability threshold.

NOTE 6 – The objectives given in Table 1 are given in terms of percentage of the worst month. These monthly percentages correspond to the following yearly percentages:

- 10% of a month = 4.0% of year;
- 2% of a month = 0.6% of year;
- 0.2% of a month = 0.04% of year.

NOTE 7 – In order to comply with Table 1 at frequencies greater than 10 GHz, it may be advantageous to make use of fade countermeasures including adaptive forward error correction (FEC) coding, power control or site diversity. Information on site diversity operation is given in Annex 1, Recommendation ITU-R S.1061.

NOTE 8 – The preferred method of verifying digital satellite link performance is on the basis of in-service measurements. These measurements would utilize the block error detection schemes, which are related to the inherent SDH block size and structure of the transmission system. FEC, scrambling and differential encoding have an impact on interpretation of the measurements (see Annex 2, § 3).

NOTE 9 – The error performance described in Table 1 was developed based on the use of an HRDP in the international portion of the link (e.g. switched international gateway-to-switched international gateway). Other applications of the HRDP within the connection are possible (e.g. end office-to-end office) and the error performance objectives can be adjusted accordingly.

NOTE 10 – The methods described in this Recommendation may be applied to the design of satellite links in private networks.

NOTE 11 – The performance objectives shall be met for the required transmission rate not for any higher rate created to support multiplexing or error correction. For instance, if the transmission rate over a satellite link is 6 Mbit/s and the required transmission rate between the end points is 2 Mbit/s, then the performance objectives for 2 Mbit/s transmission apply.

ANNEX 1

1 General

ITU-T Recommendation G.828 defines error performance parameters and objectives for international synchronous digital paths which are intended to carry SDH and ATM traffic. This Recommendation adopts all the definitions parameters and objectives defined therein. The objectives given in ITU-T Recommendation G.828 are defined as being independent of the physical network supporting the path.

In-service measurement of error rates at the SDH layer is supported by bit interleaved parity (BIP) codes carried in the SDH container headers.

1.1 Definitions

For convenience, the definitions in ITU-T Recommendation G.828 are repeated here.

Error performance measurements are based upon blocks whose size is consistent with the SDH frame structure and varies according to the bit rate, see Table 2.

1.1.1 A block

A block is a set of consecutive bits associated with the path; each bit belongs to one and only one block. Consecutive bits may not be contiguous in time.

1.1.2 Error events

- Errored block (EB): A block in which one or more bits are in error.
- Errored second (ES): A 1 s period with one or more EBs or at least one defect. Defects and related performance criteria are listed in Annex B of ITU-T Recommendation G.828.
- Severely errored second (SES): A 1 s period which contains $\geq 30\%$ EBs or at least one defect. SES is a subset of ES. To simplify measurements, the defect is used in the definition of SES instead of defining SES directly in terms of severe bit errors. However, it should be appreciated that there may exist error patterns that would not trigger a defect. Field experience will establish if this is a major problem in measuring errors.
- Background block error (BBE): An EB not occurring as part of an SES.
- Severely errored period (SEP): A sequence of between 3 and 9 consecutive SESs. The period is terminated by a second that is not a SES. Thus the SEP event is the same as the consecutive SES (CSES) event, as defined in ITU-T Recommendation G.784, with the lower threshold set to 3 s.

Table 2 gives the relationships between block sizes, bit rates, error detection code (EDC) and path types.

TABLE 2

Block sizes versus bit rates

Bit rate (kbit/s)	Path type	SDH block size used in ITU-T Recommendation G.828 (bits)	EDC
1 664	VC-11, TC-11	832	BIP-2
2 240	VC-12, TC-12	1 120	BIP-2
6 848	VC-2, TC-2	3 424	BIP-2
48 960	VC-3, TC-3	6 120	BIP-8
150 336	VC-4, TC-4	18 792	BIP-8
601 344	VC-4-4c, TC-4-4c	75 168	BIP-8
2 405 376	VC-4-16c, TC-4-16c	300 672	BIP-8
9 621 504	VC-4-64c, TC-4-64c	1 202 688	BIP-8

1.1.3 Error performance parameters

Error performance should only be evaluated whilst the path is in the available state. For a definition of the entry/exit criteria for the unavailable state, see ITU-T Recommendation G.828, Annex A.

- Errored second ratio (ESR): The ratio of ES to total seconds in available time during a fixed measurement interval.
- Severely errored second ratio (SESR): The ratio of SES to total seconds in available time during a fixed measurement interval.
- Background block error ratio (BBER): The ratio of BBE to total blocks in available time during a fixed measurement interval. The count of total blocks excludes all blocks during SESs.
- Severely errored period intensity (SEPI): The number of SEP events in available time, divided by the total available time in seconds. Thus the SEPI parameter has a unit of 1/s.

1.1.4 Block based measurements

Each block is monitored by means of a BIP EDC carried in the SDH header. When an error state is detected, it is not possible to determine whether a block or its controlling EDC bits are in error. Therefore if there is a discrepancy between the EDC and its controlled block, it shall always be assumed that the block is in error.

2 Error performance objectives

2.1 End-to-end objectives

Table 3 specifies the end-to-end objectives for a 27 500 km hypothetical reference path (HRP). The objectives applicable to a real path are derived from Table 3 using the allocation principles detailed in § 6.2 of ITU-T Recommendation G.828. Each direction of the path shall independently satisfy the allocated objectives for all parameters. The objectives are long-term objectives to be met over an evaluation period of typically 30 consecutive days.

Synchronous digital paths operating at bit rates covered by this Recommendation may be carried by digital sections operating at higher bit rates. Such systems must meet their end-to-end objectives. For example, in SDH, an STM-1 section may carry a VC-4 path and therefore the STM-1 section should be designed to ensure compliance with the objectives of the VC-4 path.

Objectives are allocated to the national and international portions of a path. In the above example, if the STM-1 section does not form a complete national or international portion, the corresponding national/international allocation must be subdivided to determine the appropriate allocation for the digital section. This is outside the scope of this Recommendation.

TABLE 3

**End-to-end error performance objectives for a 27 500 km
international synchronous digital HRP as defined
in ITU-T Recommendation G.828**

Bit rate (kbit/s)	Path type	Blocks/s	ESR	SESR	BBER ⁽¹⁾	SEPI ⁽²⁾
1 664	VC-11, TC-11	2 000	0.01	0.002	5×10^{-5}	0.0002/s
2 240	VC-12, TC-12	2 000	0.01	0.002	5×10^{-5}	0.0002/s
6 848	VC-2, TC-2	2 000	0.01	0.002	5×10^{-5}	0.0002/s
48 960	VC-3, TC-3	8 000	0.02	0.002	5×10^{-5}	0.0002/s
150 336	VC-4, TC-4	8 000	0.04	0.002	1×10^{-4}	0.0002/s
601 344	VC-4-4c, TC-4-4c	8 000	⁽³⁾	0.002	1×10^{-4}	0.0002/s

- (1) This BBER objective corresponds to an equivalent BER of 8.3×10^{-10} , an improvement over the BER of 5.3×10^{-9} for the VC-4 rate. Equivalent BER is valuable as a rate-independent indication of error performance, as BBER objectives cannot remain constant as block sizes increase.
- (2) Provisional value requiring further study.
- (3) ESR objectives tend to lose significance for high bit rates and are therefore not specified for paths operating above 160 Mbit/s. However, a significant increase in ESR indicates a degrading transmission system. Therefore, for maintenance purposes ES monitoring should be implemented.

2.2 Apportionment of end-to-end objectives

The levels of performance expected are apportioned between international and national portions of an HRP.

Further subdivision of these objectives is beyond the scope of this Recommendation.

2.2.1 Allocation to the national portion

Each national portion is allocated a fixed allowance of 17.5% of the end-to-end objective plus a distance-based allocation.

When a national portion includes a satellite hop, a total allowance of 42% of the end-to-end objectives in Table 3 is allocated to this national portion. The 42% allowance completely replaces both the distance-based allowance and the 17.5% block allowance.

2.2.2 Allocation to the international portion

Independent of the distance spanned, any satellite hop in the international portion receives a 35% allocation of the objectives in Table 3. The 35% allowance completely replaces all distance-based and block allowances given to parts of the international portion spanned by the satellite hop.

3 Satellite HRDP performance objectives

TABLE 4

**Satellite HRDP performance objectives
for an international SDH link**

Rate (kbit/s)	1 664 (VC-11)	2 240 (VC-12)	6 848 (VC-2)	48 960 (VC-3)	150 336 (VC-4)	601 334 (VC-4-4c)
ESR	0.0035	0.0035	0.0035	0.007	0.014	(1)
SESR	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
BBER	1.75×10^{-5}	1.75×10^{-5}	1.75×10^{-5}	1.75×10^{-5}	0.35×10^{-4}	0.35×10^{-4}

- (1) Due to the lack of information on the performance of paths operating above 160 Mbit/s, no ESR objectives are recommended at this time. Nevertheless, ESR processing should be implemented within any system operating at these rates for maintenance or monitoring purposes.

ANNEX 2

BEP mask derivation

1 Introduction

The parameters and objectives defined in ITU-T Recommendation G.828 are not directly appropriate for satellite transmission system design. They must be transformed into a BEP versus percentage-of-time distribution, also called a BEP mask, in such a way that any digital transmission system designed to meet the mask would also meet the objectives of the Recommendation. The transform explained in this Annex, however, does not result in one unique mask.

This Annex explains the methodology for creating a BEP mask.

2 Probability of the basic events

It is well known that transmission errors over satellite links occur in bursts where the average number of errors per burst is, among other factors, a function of the scrambler and the FEC code. Consequently, a successful model of the digital performance over satellite links has to take into account this bursty nature.

One statistical model that can adequately represent the random occurrence of bursts is the Neyman-A contiguous distribution, where the probability of k errors occurring in N bits, $P(k)$, is:

$$P(k) = \frac{\alpha^k}{k!} e^{-\frac{BEP \cdot N}{\alpha}} \sum_{j=0}^{\infty} \frac{j^k}{j!} \left(\frac{BEP \cdot N}{\alpha} \right)^j e^{-j\alpha}$$

where:

α : average number of errored bits in a burst of errors

BEP : bit-error probability.

If $N = N_B$ is taken as the number of bits in a block of data, then the probability of zero errors in a block is:

$$P(0) = e^{-\frac{BEP \cdot N_B}{\alpha}} \sum_{j=0}^{\infty} \left[\left(\frac{BEP \cdot N_B}{\alpha} \right)^j / j! \right] e^{-j\alpha} \cong e^{-\frac{BEP \cdot N_B}{\alpha}} \text{ for all practical values of } \alpha.$$

The probability of an errored block, P_{EB} , is then given by:

$$P_{EB} = 1 - P(0) = 1 - e^{-\frac{BEP \cdot N_B}{\alpha}} = 1 - e^{-N_B \cdot BEP_{CRC}(t)}$$

where $BEP_{CRC}(t) = BEP/\alpha$, and the BEP_{CRC} is explicitly shown as a function of time. The probability of an ES, $P_{ES}(t)$, can then be expressed as:

$$P_{ES}(t) = 1 - e^{-n \cdot P_{EB}(t)}$$

where n is the number of blocks per second.

Since the probability of k errored blocks in a total of n blocks, $P_{n,k}(t)$, is given by:

$$P_{n,k}(t) = \frac{n!}{(n-k)!k!} (1 - P_{EB}(t))^{n-k} P_{EB}^k(t)$$

then, the probability of an SES, $P_{SES}(t)$, is:

$$P_{SES}(t) = \sum_{k=0.3n}^n P_{n,k}(t) = 1 - \sum_{k=0}^{0.3n-1} P_{n,k}(t) = 1 - \sum_{k=0}^{0.3n-1} \frac{n!}{(n-k)!k!} (1 - P_{EB}(t))^{n-k} P_{EB}^k(t)$$

2.1 Generation of masks

Assuming a general form of the mask, as in Fig. 1, and using the probability formula the ESR (defined as the total ES, i.e. seconds with one or more errored blocks) divided by the total available seconds, T_a , is given by:

$$ESR = \frac{\int P_{ES}(t) dt}{T_a}$$

Similarly, the SESR is given by:

$$SESR = \frac{\int P_{SES}(t)}{T_a}$$

If $P_{ES}(t)$ and $P_{SES}(t)$ are assumed to be piece-wise constant in time, then ESR and SESR can be expressed as:

$$ESR = \sum_{i=1}^M P_{ES_i} \cdot \Delta t_i$$

and

$$SESR = \sum_{i=1}^M P_{SES_i} \cdot \Delta t_i$$

where M is the total number of time intervals, $P_{ES_i}(t)$ and $P_{SES_i}(t)$ are the probability of an ES and SES respectively in the i -th time interval divided by T_a .

BBER is defined as the ratio between EBs to the total blocks during available seconds, excluding all blocks during SES. Thus:

$$BBER = \frac{\int_{T_a} \left(\sum_{k=1}^{0.3n} P_{n,k}(t) \cdot k \right) dt}{n \cdot \left(T_a - \int_{T_a} P_{SES}(t) \cdot dt \right)} = \frac{\sum_{k=1}^{0.3n} \left(\frac{1}{T_a} \int_{T_a} P_{n,k}(t) \cdot dt \right) \cdot k}{n \cdot (1 - SESR)}$$

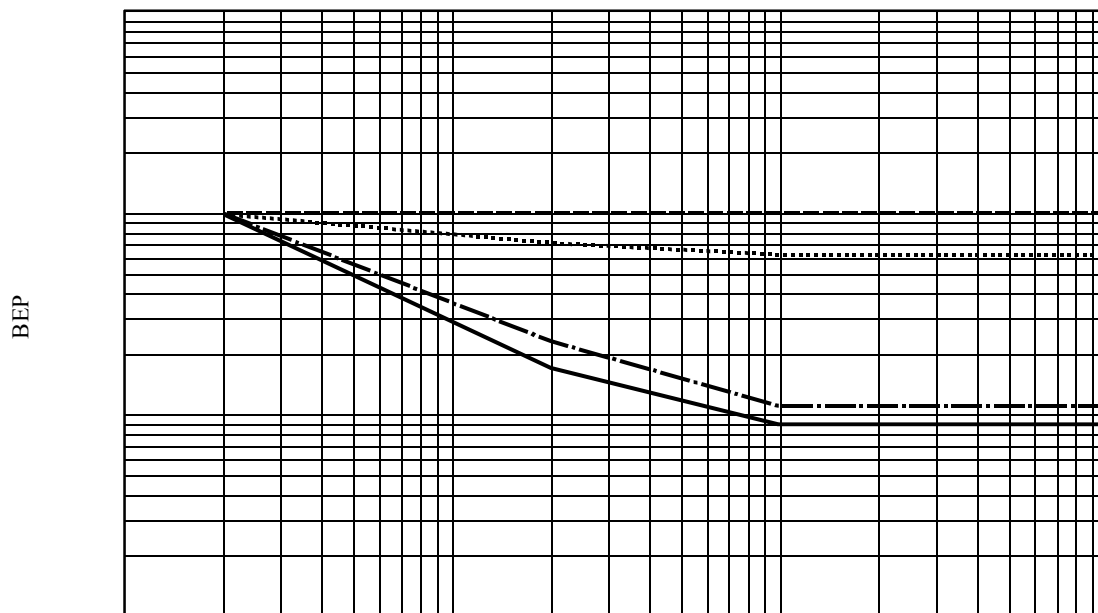
If $\overline{P_{n,k}} = \frac{\int P_{n,k} \cdot dt}{T_a}$ is set, then BBER can be expressed as:

$$BBER = \frac{\sum_{k=1}^{0.3n} \overline{P_{n,k}} \cdot k}{n \cdot (1 - SESR)}$$

In selecting the value of BEP_{th}/α for the generation of the masks, however, the occurrence of incorrect pointer interpretations (IPI), which is crucial to the proper operation of SDH links, must be considered. Measurements have shown that IPI increases significantly at or beyond a BEP of approximately 1×10^{-7} , which is significantly lower than that at which satellite modems experience loss of synchronization. In view of this, further study will be required to define a BEP threshold for

Using the above process with the additional assumptions that BEP/α corresponding to points C and D are the same, an example set of masks for various transmission rates was generated and is shown in Fig. 2.

FIGURE 2
Generated masks for satellite hops



Total time

----- 1.664 and 2.24 Mbit/s	-.-.-.-.- 48.96 Mbit/s
..... 6.848 Mbit/s	————— 150.336 Mbit/s

$\alpha = 10$
 BEP threshold time is 1×10^{-8}
 Available time from 0.002 to 1
 All models outperform BBER criteria
 Model for 1.664 and 2.24 Mbit/s also outperform ESR criteria

1521-02

3 Relationship between BER and error-event ratio

It is well known that errors on satellite links employing FEC and scrambler schemes tend to occur in clusters. The appearance of the clusters, which can also be called error events, is random following a Poisson distribution. The resulting block error rate is the same as if it were caused by randomly (Poisson distributed) occurring bit errors with a BER, BER/α , where α (used in § 2.1 to account for the burstiness of errors) is the average number of errored bits within a cluster, α also represents the ratio between the BER and error-event ratio.

Statistical properties of the clusters of errors are dependent on the FEC/scrambler scheme used. Computer simulations and measurements of various FEC schemes (without scrambler or differential encoding) were used to determine the factor α . These results are given in Table 5.

Laboratory measurements of the INTELSAT IDR type digital transmissions (FEC, $R = 3/4$ plus scrambler) led to an $\alpha = 10$ over the range of 1×10^{-4} to 1×10^{-11} BER. An $\alpha = 5$ was determined in the same measurements for the INTELSAT IBS type digital transmissions (FEC, $R = 1/2$ plus scrambler).

The results of the measurements indicate that α could be in a range of 1 to 10.

Further studies of other types of FEC/scrambler schemes are required.

The impact of parameter α on the performance model could be assessed as follows.

TABLE 5

Factor, α , for various FEC schemes

Bit rate (kbit/s)	Without FEC	With FEC		
		1/2	3/4	7/8
1 664	1.0	2.7	5.1	6.6
2 240	1.0	3.4	6.8	8.2
6 848	1.0	2.6	5.1	7.0
48 960	1.0	2.8	5.4	7.2
150 336	1.1	2.8	4.9	7.2

The masks in Fig. 2 were generated using $\alpha = 10$. If, for example, no FEC/scrambler ($\alpha = 1$) were used, the models would be shifted by one decade and the BER requirements would be more stringent by one decade.

4 Conclusions

Studies have shown that the masks required to meet the requirements of ITU-T Recommendation G.828 are transmission rate dependent.

The design masks are also dependent on the error distribution, which in turn are influenced by the FEC/scrambler scheme employed.

Service requirements also need to be taken into account in deriving the design masks.